(11) (A) No. 1 124 781
(45) ISSUED 820601

(52) CLASS 318-78

(51) INT. CL.$^{3}$ H02P 1/00

# (19) (CA) CANADIAN PATENT (12)

(54) CONTROL CIRCUIT FOR DISCHARGING THE FIELD WINDING OF A SYNCHRONOUS MOTOR

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(21) APPLICATION No. 315,582

(22) FILED 781031

No. OF CLAIMS 8

## ABSTRACT OF THE DISCLOSURE

This invention relates to a control circuit for a rotor field winding of a synchronous motor. During motor acceleration at start-up, the rotor winding is discharged through a pair of thyristors connected in series across the rotor field winding. A varistor and a resistor are also connected in series across the rotor field winding and the junction between the varistor and resistor is connected by separate paths to each thyristor gate. As the voltage in the field winding increases, the varistor-resistor combination will conduct more current. When the voltage drop across the varistor reaches a first level it is sufficient to fire one thyristor. A zener diode in the path to the gate of the other thyristor blocks firing of that thyristor until the voltage across the varistor rises above the breakdown voltage of the zener, then the other thyristor fires. When both thyristors are fired or gated on they discharge the rotor winding. It was previously necessary to arrange for successive firing of the thyristors by using a pair of zeners whose breakdown voltage was selected by trial and error to ensure sequential firing at desired voltages. The present invention eliminates the need for selecting these matched but mismatched zeners and the related expense.

This invention relates to a control circuit for a rotor field winding of a synchronous motor which is used during motor starting to discharge the field winding.

During motor starting AC is applied to the stator winding of the synchronous motor and the motor is run as an induction motor until the motor speed approaches 94 to 99% of synchronous speed. At this time excitation is applied to the rotor field winding to bring the motor into synchronism. The acceleration of the rotor from standstill to near synchronism induces an alternating voltage on the field winding. During this period of acceleration it is necessary to short circuit the rotor field winding in order to keep the induced voltage from rising to destructive levels.

One known manner in which to discharge the rotor field winding is to short circuit the winding by a series connected pair of thyristors parallelling the winding. The firing of the thyristors is controlled by a pair of zener diodes. One example of such a control circuit is depicted in Canadian Patent No. 729,362 issued August 13, 1968 to J.D. Edwards. Bridge rectifiers of a control circuit are connected in the same direction across two conductors of the circuit. A pair of thyristors are connected in series in the same direction across the conductors thus parallelling the rotor field winding. The direction of the thyristors is opposite to that of the bridge diodes. The gate electrodes of each thyristor are connected to a respective anode electrode of each zener diode. The cathode electrodes of each zener diode are connected to the conductor of the control circuit which becomes positive when the circuit is operating under normal synchronous running. During the acceleration of the

synchronous motor the negative portion of the AC induced voltage is discharged by the bridge rectifiers. During the acceleration the positive portion of the AC induced voltage is discharged through the pair of thyristors when the induced voltage exceeds the reverse breakdown voltge of the zener diodes. Once the reverse breakdown voltage of the zener diodes is exceeded a current flow path is provided from the conductor to the gate terminals of each thyristor which fires or turns on the thyristors. When the thyristors turn on, the positive portion of the induced voltage in the field winding discharges through the thyristors and thereby short circuits the field winding. In order to excite the field winding it is necessary that the thyristors do not turn on during normal synchronous running. Because the turning on of the thyristors is controlled by the zener diodes, the reverse breakdown voltage of each zener diode will be larger than excitation voltages present on the conductors of the control circuit during normal synchronous running.

Although the aforementioned Canadian Patent to Edwards does not teach staggered firing of the thyristors, in practise it is desirable not to attempt simultaneous firing of the thyristors. Firing of the thyristors at the same instant in time is highly improbable and may result in one thyristor turning on and off before the other thyristor turns on. This is a problem because the field winding will not be discharged which may result in it being damaged by excessively high voltage levels. To avoid this problem one thyristor is fired just before the other. Because rapid rises in voltage may cause a thyristor to fire below its holding voltage, the thyristor connected directly to the conductor which is positive during normal synchronous motor running is to be fired or turned on

subsequent to the other thyristor. In order to arrange the successive firing of the thyristors, the zener diodes of the Edwards patent must be selected to have their breakdown voltages slightly different with respect to one another. This will involve great lengths of time in testing the zener diodes to ensure their breakdown voltages are matched but mismatched voltages.

It is therefore a feature of this invention to provide a control circuit for a field winding of a synchronous motor that eliminates the need for selecting these matched but mismatched zener diodes and the related expense.

Briefly, the present invention controls the firing of first and second thyristors by employing a non-linear voltage dependent device and resistance device. Current passing through the non-linear device rises rapidly when the voltage on the rotor field winding is above a first predetermined voltage. The voltage at a junction formed between the non-linear device and resistance device is related to the conduction of the non-linear device. When the voltage at the junction exceeds a second predetermined voltage greater than or equal to the first predetermined voltage, a limited current path is provided from the junction to the first thyristor's gate electrode which turns on the first thyristor. When the voltage at the junction exceeds a third predetermined voltage greater than the second predetermined voltage, a current path is provided from the junction to the second thyristor's gate electrode to turn on the second thyristor. With both thyristors turned on a path is provided therethrough to discharge the winding. The use of the non-linear device is significant in that it may be readily manufactured to meet specific motor requirements.

The non-linear device of this invention may include a device that has a condition which may be referred to as "non-conducting". When the non-linear device is operating in this non-conducting condition, it should be understood that this device is conducting relatively low current. When the current passing through the non-linear device rises rapidly after the voltage on the winding exceeds the first predetermined voltage, the current to voltage relationship may be a linear or non-linear relationship.

Therefore according to one aspect of the invention there is provided a control circuit for a rotor field winding of a synchronous motor that discharges induced voltages on the winding during motor start-up, comprising: a first and a second thyristor connected in series across the winding and arranged in the same direction, each thyristor having a gate electrode; a non-linear device and a resistance device connected in series across the winding; a junction formed between the non-linear device and the resistance device; a first electrical means connected between the junction and the gate electrode of the first thyristor providing a first path for limited current flow to the gate of the first thyristor causing the first thyristor to fire when voltages at the junction exceed a first predetermined voltage; a second electrical means connected between the junction and the gate of the second thyristor providing a second path for current flow to the gate of the second thyristor causing the second thyristor to fire when the voltages at the junction increase to a second predetermined voltage slightly above the first predetermined voltage; the first and second predetermined voltages being related to the induced

voltage; and the firing of both of the first and second thyristors providing a path to discharge the winding.

According to another aspect of the invention, there is provided a control circuit for a rotor field winding of a synchronous motor, comprising: a first and a second thyristor connected in series across the field winding and arranged in the same direction, each thyristor having a gate electrode; a non-linear voltage dependent device and a resistance device connected in series across the winding, the non-linear device having a current which increases rapidly above a first predetermined voltage on the winding providing at a junction between the non-linear device and the resistance device voltage related to the conduction of the non-linear device; a first electrical means connected between the junction and the gate electrode of the first thyristor providing a first path for limited current flow to the gate electrode of the first thyristor causing the first thyristor to fire when the voltage at the junction increases to a second predetermined voltage no less than the first predetermined voltage; a second electrical means connected between the junction and the gate of the second thyristor providing a second path for current flow to the gate of the second thyristor causing the second thyristor to fire when the voltage is slightly in excess of the second predetermined voltage; and, the firing of both the first and second thyristors providing a path to discharge the winding.

For a better understanding of the nature and objects of the invention reference may be had, by way of example, to the accompanying ~~diagramatic~~ diagrammatic drawing.

The preferred embodiment of the invention is shown in the figure. Control circuit 10 has a pair of conductors

12 and 14 across which rotor field winding 16 is connected. Voltage induced on the field winding 16 during the motor's acceleration from standstill to near synchronism is discharged through parallel path 18 shown connected across conductors 12 and 14. This occurs when first and second thryristors, 20 and 22, are turned on or fired. The thyristors 20 and 22 are shown arranged in the same direction.

Looking now to the left of control circuit 10, three phase AC excitation may be applied to the control circuit by lines 24a, 24b and 24c. These lines are connected to a bridge rectifier circuit 26 which causes the voltage on conductor 12 to be a positive DC voltage and the voltage on conductor 14 to be a negative DC voltage. These positive and negative DC voltages are only present on conductors 12 and 14 when the excitation is applied. The excitation is applied when the rotor approaches synchronous speed. As is well know, excitation is not applied during starting until a desired motor speed is reached and consequently the source of excitation does not represent part of the control circuitry 10 insofar as the operation of the invention is concerned.

In the preferred embodiment the voltage dependent non-linear device comprises a varistor 28 and the resistance device comprises resistor 30. Current passing through varistor 28 rises rapidly as the voltage induced on the winding 16 goes above a first predetermined amount. The first predetermined voltage is chosen to be higher than voltages experienced on the field winding during normal synchronous running and lower than voltages that would prove to be destructive to the winding. Varistor 28 and resistor 30 are shown connected in series across conductor 12 and 14. Because current passing through

varistor 28 rises rapidly as the voltage on winding 16 exceeds the first predetermined amount, control circuit 10 may be susceptible to current spikes. Capacitor 32 shown in parallel with resistor 30 protects control circuit 10 from positive spikes which may impede or damage the operation of the circuit. Diode 34 which parallels capacitor 32 and resistor 30 protects capacitor 32 from negative spikes.

The voltage at junction 36 shown between varistor 28 and resistor 30 is dependent upon the conduction of varistor 28. Due to the presence of resistor 30, voltage at junction 36 is permitted to increase above the first predetermined voltage. A first electrical means provides a limited current path from junction 36 through diode 38 and resistor 40 to the gate electrode 42 of first thyristor 20 only when the voltage at junction 36 is at a second predetermined voltage no less than the first predetermined voltage. When this limited current path is provided to gate electrode 42 thyristor 20 will fire or be turned on. Because varistor 28 passes small amounts of current when operating in the condition referred to as "non-conducting", diode 38 reduces the risk of thyristor 20 turning on when the varistor is operating in its non-conducting condition. Resistor 40 limits current flow to gate electrode 42 and permits voltage at junction 42 to increase above the second predetermined voltage. Resistor 44 increases the holding capacity of thyristor 20.

When the voltage at junction 36 reaches a third predetermined voltage greater than the second predetermined voltage a second electrical means comprising diode 46 and zener diode 48 provides a current path to gate electrode 50 of second thyristor 22 which will cause

thyristor 22 to fire or be turned on. With thyristors 20 and 22 turned on the field winding may be discharged along path 18. Diode 46 has a function similar to diode 38 which is to reduce the risk of thyristor 22 firing when varistor 28 is operating in its "non-conducting" condition. Zener diode 48 is chosen to block current flowing to gate 50 of thyristor 22 when the voltages below the third predetermined voltage are present at junction 36. The reverse breakdown voltage of zener 48 is chosen so that zener 48 conducts when the voltage at junction 36 exceeds the third predetermined voltage. Resistor 52 is a gate to cathode by-pass resistor which increases the current holding capacity of thyristor 22.

Conductor 54 joins line 24c with a point 56 between thyristors 20 and 22 so as to reduce the risk of both thyristors firing when the rotor field winding is being excited during normal synchronous operation. It is important that thyristors 20 and 22 do not turn on or fire during normal synchronous operation because if they did turn on the excitation to the field winding would be short-circuited. This would result in the loss of synchronism.

The operation of control circuit 10 during the starting of the motor is now described. During the motor acceleration from standstill an AC voltage is induced on winding 16. The negative portion of this AC voltage is discharged through bridge rectifier circuit 26. The source of excitation is isolated from control circuit 10. As the positive portion of AC induced voltage increases to a first predetermined voltage, varistor 28 changes from the "non-conducting" condition to a conducting condition. The first predetermined voltage exceeds any excitation

voltage normally experienced by conductor 12 during synchronous running. There is presently no current path to either of gate terminals 42 and 50. Resistor 30 permits voltage present at junction 36 to continue to increase while varistor 28 is conducting. As this positive portion of induced voltage rises to a second predetermined voltage not less than the first predetermined voltage a limited current path from junction 36 to gate 42 fires thyristor 20 and holds it on. In the preferred embodiment resistors 30 and 40 are chosen so that the first current path is provided when varistor 28 fires (i.e.: the second predetermined voltage is equal to the first predetermined voltage). Zener 48 continues to block current flow to gate 50 from junction 36. Due to the limited current path and resistor 30 voltage builds at junction 36 until a third predetermined voltage is reached by the positive portion of the AC voltage on winding 16. At this time zener diode 48 breaks down and a current path is provided from junction 36 to gate 50 which fires thyristor 22. This third voltage is preferably about 1% greater than the second voltage. In this manner thyristors 20 and 22 are turned on in sequential fashion so as to provide a path to discharge the AC voltage on winding 16.

The foregoing has been a description of the preferred embodiment of the present invention. It should be understood that variations can be made therefrom. One variation may be that instead of one varistor two or more varistors may be used in parallel. Accordingly the invention is to be limited to the accompanying claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A control circuit for a rotor field winding of a synchronous motor that discharges induced voltages on said winding during motor start-up, comprising:

a first and a second thyristor connected in series across said winding and arranged in the same direction, each thyristor having a gate electrode;

a non-linear device and a resistance device connected in series across said winding;

a junction formed between said non-linear device and said resistance device;

a first electrical means connected between said junction and the gate electrode of said first thyristor providing a first path for limited current flow to the gate of said first thyristor causing said first thyristor to fire when voltages at said junction exceed a first predetermined voltage;

a second electrical means connected between said junction and the gate of said second thyristor providing a second path for current flow to the gate of said second thyristor causing said second thyristor to fire when the voltages at said junction increase to a second predetermined voltage slightly above the first predetermined voltage;

said first and second predetermined voltages being related to said induced voltage; and

the firing of both of said first and second thyristors providing a path to discharge said winding.

2. A control circuit for a rotor field winding of a synchronous motor, comprising:

a first and a second thyristor connected in series across said field winding and arranged in the same direction, each thyristor having a gate electrode;

a non-linear voltage dependent device and a resistance device connected in series across said winding, said non-linear device having a current which increases rapidly above a first predetermined voltage on said winding providing at a junction between said non-linear device and resistance device a voltage related to the conduction of said non-linear device;

a first electrical means connected between said junction and the gate electrode of said first thyristor providing a first path for limited current flow to the gate electrode of the first thyristor causing said first thyristor to fire when the voltage at said junction increases to a second predetermined voltage no less than the voltage related to the conduction of said non-linear device;

a second electrical means connected between said junction and the gate of said second thyristor providing a second path for current flow to the gate of said second thyristor causing said second thyristor to fire when the voltage at said junction increases to a third predetermined voltage slightly in excess of said second predetermined voltage; and

the firing of both of said first and second thyristors providing apath to discharge said winding.

3. The circuit of claim 2 wherein the non-linear device comprises a varistor.

4. The circuit of claim 2 wherein the non-linear device comprises two or more varistors arranged in parallel.

5. The circuit of claim 2 wherein the first



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electrical means includes a resistor.

6. The circuit of claim 2 wherein the second electrical means includes a zener diode having a reverse breakdown voltage corresponding to the third predetermined voltage.

7. The circuit of claim 6 wherein the third predetermined voltage is about 1% greater than the second predetermined voltage.

8. A control circuit for a rotor field winding of a synchronous motor comprising:

a first and second thyristor connected in series across said winding and arranged in the same direction, each thyristor having a gate electrode and a gate to cathode by-pass resistor increasing the thyristor's holding capacity;

a bridge rectifier circuit connected in series across said winding and arranged in a direction opposite to the direction of said thyrsitors;

a varistor and first resistor connected in series across said winding, said varistor having a current which increases rapidly above a first predetermined voltage on said winding, said varistor having a non-conducting condition when said current does not increase rapidly, when said current rises rapidly said varistor providing at a junction between said varistor and first resistor a voltage related to the conduction of said varistor;

a first electrical means comprising a first diode having an anode electrode connected to said junction and a cathode terminal connected to a second resistor, said second resistor being connected to the gate terminal of said first thyristor, said first electrical means providing a first path for limited current flow to the gate electrode of said first thyristor causing said first thyristor to

Claim 8 continued:

fire when the voltage at said junction exceeds a second predetermined voltage no less than the voltage related to the conduction of the varistor, said first diode reducing risk of said first thyristor firing when said varistor is in said non-conducting condition;

a second electrical means comprising a second diode and zener diode each having an anode and cathode electrode; the anode electrode of said second diode being connected to said junction, the cathode electrode of said second diode and zener diode being joined, the anode electrode of said zener diode being connected to the gate electrode of said second thyristor, said second electrical means providing a second path for current flow to the gate of said second thyristor causing said second thyristor to fire when the voltage at said junction increases to a third predetermined voltage slightly in excess of said second predetermined voltage, said zener diode having a breakdown voltage determining said third predetermined voltage; and

the firing of both said first and second thyristors providing a path to discharge said winding.

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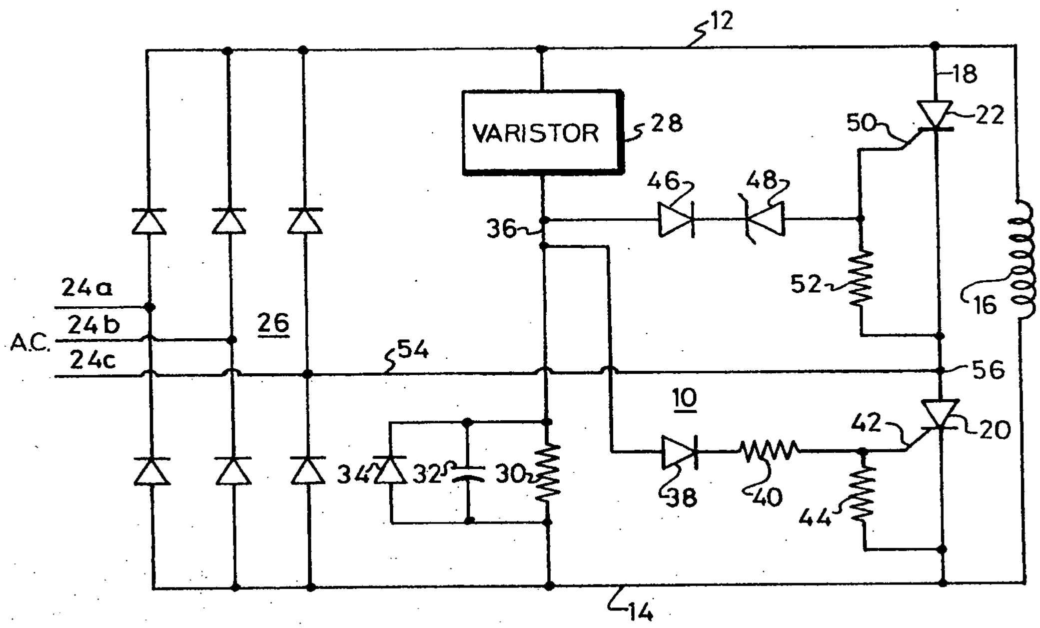


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